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ECLOGITIC AND PERIDOTITIC DIAMOND FORMATION (KIMBERLEY POOL KIMBERLITES, SOUTH AFRICA) AS EVIDENCED FROM C-, N- STABLE ISOTOPE : A MAIN MANTLE-DERIVED SOURCE.

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INTRODUCTION

Whether lithospheric (i.e. 150-250 km deep) eclogitic and peridotitic diamonds grew from isotopically-similar melt(s) and/or fluid(s) deriving from the convective asthenosphere is still a subject of debate. Some authors conclude that the ¹³C-depleted signature of eclogitic diamonds testifies of a subduction-related diamond formation whereas others have emphasised that it rather reflects a mineralogically-controlled reaction related, in eclogite, to the lack of olivine (for discussion see e.g. Cartigny et al., 2009; Stachel et al., 2009 and ref. therein).

The present contribution addresses this question using an unprecedented number of diamonds from the Kimberley Pool kimberlites.

GEOLOGICAL BACKGROUND AND STUDIED DIAMONDS

Among the different diamondiferous kimberlites from the Kaapvaal craton, Kimberley Pool (also often referred to as De Beers Pool) are, historically, within the most famous. This is indeed there, about one century ago, following the first diamond finding in december 1866 that the modern diamond industry started (see Janse, 1995 for a review).

As shown by Figure 1, Kimberley Pool (28°45'S; 24°50'E) is a kimberlite cluster formed of five economic pipes (Bultfontein, Dutoitspan, De Beers, Kimberley and Wesselton) and uneconomic kimberlites, sills and dikes (Clement et al., 1986). The five economic pipes (only for which data are available) have emplacement ages which fall all within experimental errors (83 to 92 Ma; Allsopp and Barrett, 1975). The first study on diamond characteristics (shape, color, size, luminescence) and paragenesis from individual kimberlitic pipes has shown that diamonds have the same source region and, accordingly, that the

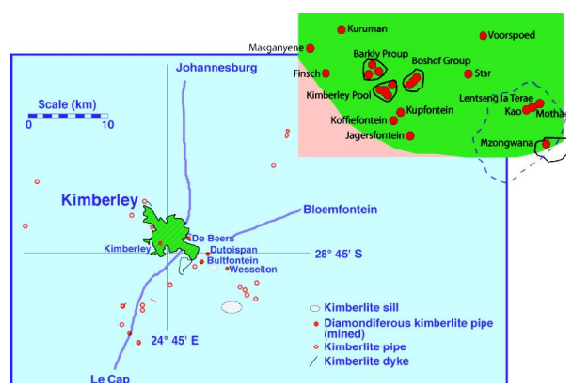


Fig. 1 : Localisation of the different diamondiferous and non-diamondiferous kimberlites, sills and dikes composing the Kimberley Pool cluster. The five historical diamondiferous pipes are indicated and are contained within a circle of eight kilometers in diameter (after Clement et al., 1986)



pipes have a same deep kimberlitic root (Harris et al., 1984), this being supported by kimberlite emplacement ages. At the date of sampling, only three kimberlites, Bultfontein, Dutoispan and Wesselton were mined. The production being grouped, it is thus not possible to distinguish the pipe from which a diamond originated.

In this study, the C-, N- isotope compositions, N-contents and N-aggregation state of an unprecedented number of silicate-bearing diamonds has been carried out. From our on-going work, we should include, at the time of the conference, sulfide bearing diamonds (which will also include the $\delta^{34}\text{S}$ and $\delta^{33}\text{S}$ values). Based on the type or chemical composition of inclusions (e.g. Figure 2), 225 samples are available (43 eclogitic and 182 peridotitic). Some peridotitic diamonds can be further classified into 83, and 20 diamonds belonging to the harzburgitic (subcalcic), lherzolitic (calcic) parageneses and allow to discuss the relationship between them.

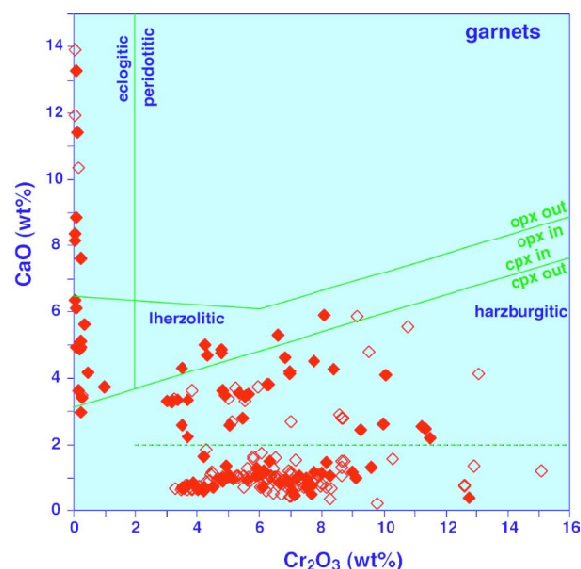
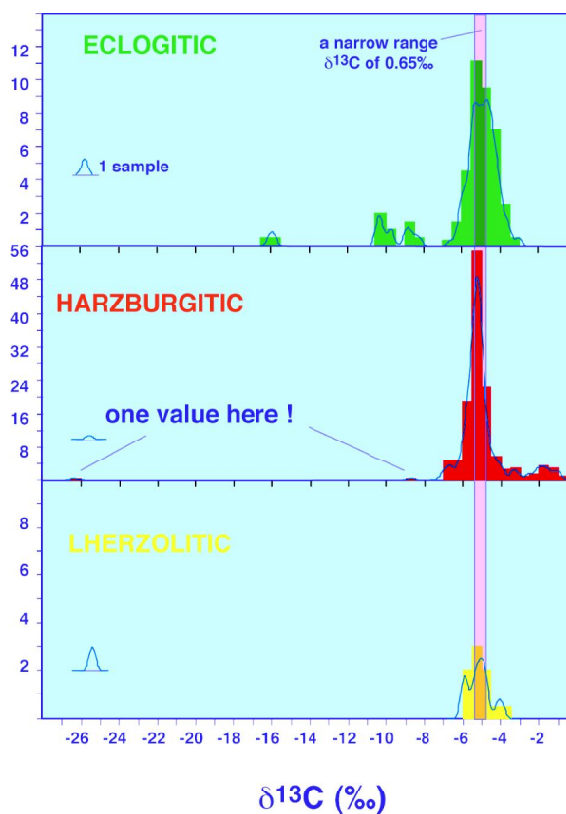


Fig. 2: Cr_2O_3 -CaO plot of garnets included in Kimberley Pool diamonds. The field defining the eclogitic, harzburgitic, lherzolitic and websteritic parageneses are shown. Filled symbols refers to samples analysed to date for stable isotopes.

RESULTS

Carbon stable isotopic compositions vary greatly from one paragenesis to the other. $\delta^{13}\text{C}$ -values of harzburgitic diamonds vary from -6.82 to -0.93‰, with a mean value of -4.66‰ and a positive skewness. $\delta^{13}\text{C}$ -values for moderately subcalcic diamonds vary from -6.90 to -3.90‰ and an extreme value down to -26.38‰ displayed by a zoned sample. The mean $\delta^{13}\text{C}$ -value is -6.22‰. Lherzolitic diamonds show $\delta^{13}\text{C}$ -values from -5.97 to -4.22‰ and a mean value of -5.13‰. Eclogitic diamonds have $\delta^{13}\text{C}$ -values contained within a -15.38 to -3.06‰ interval, with a mean





value of -5.70‰, and show a clear negative skewness. With the exception of the zoned sample mentioned above, among the duplicate $\delta^{13}\text{C}$ -analyses available, Kimberley Pool diamonds show very little $\delta^{13}\text{C}$ -variability.

Sixty-two of the 182 harzburgitic diamonds were classified as Type I. All the nitrogen-bearing diamonds were combusted for coupled $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N determinations, but only 51 harzburgitic diamonds allowed a $\delta^{15}\text{N}$ analysis. As shown by Figure 7, these have $\delta^{15}\text{N}$ -values covering a range of H² 20‰ from -12.3 to +8.1‰, most of the data (i.e. 70%) being concentrated within a -6 to +3‰ interval. The mean $\delta^{15}\text{N}$ value is negative at about -0.3‰. Relative to previous studies, harzburgitic diamonds from Kimberley Pool show more often positive (~ 54 %) than negative $\delta^{15}\text{N}$ -values. The distribution is also unique as the main

mode of the $\delta^{15}\text{N}$ -distribution is centered around +1‰ (see figure 6). It may be tempting to suggest a bimodal distribution of harzburgitic $\delta^{15}\text{N}$ -values with a mode at H² -5‰ and a second around +1‰. Such a distinction is however not supported by distinct chemical composition of the enclosed inclusions (not shown) or nitrogen aggregation states (Fig. 4). As illustrated by Figure 6, it is worth noting that positive $\delta^{15}\text{N}$ -values displayed by harzburgitic diamonds are generally associated with lower nitrogen contents (e.g. < 350 ppm), whereas diamonds with higher nitrogen contents tend to be characterised by negative $\delta^{15}\text{N}$ -values. Among duplicate $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N analyses (n = 12; Table 2) diamonds show, overall, good agreements between to the two $\delta^{13}\text{C}$ (< 0.6‰, n = 11), $\delta^{15}\text{N}$ (< 2‰, n = 18) and N-content (< 200 ppm, n = 15) values. Moreover, as harzburgitic diamonds which

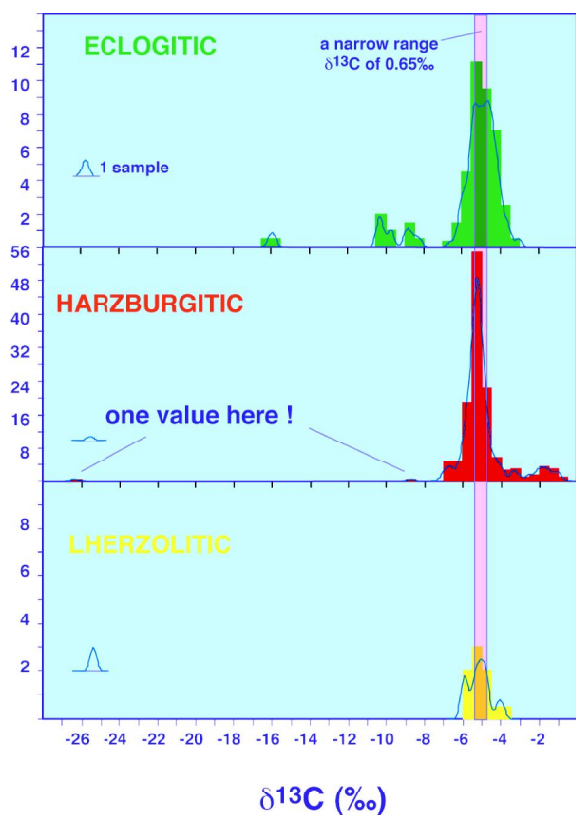


Fig. 3 : C-isotope distributions of eclogitic, harzburgitic and lherzolitic diamonds. Note that the modes coincide within 0.65‰.

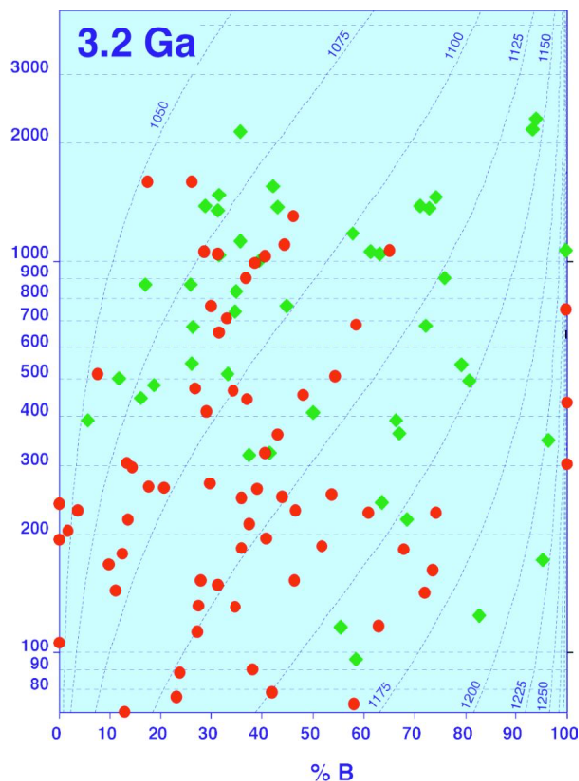


Fig. 4 : N-aggregation and N-content relationships of eclogitic and peridotitic diamonds. The diagram that diamonds of both parageneses resided at similar mantle temperatures.



show the highest $\delta^{15}\text{N}$ -values display the lowest N-contents implies that harzburgitic diamonds plotting on the right hand part of Figure 5 have only low nitrogen content. The single lherzolitic Type I diamond yielded two very consistent $\delta^{15}\text{N}$ -values of H² -3.1‰ (Tables 1 and 2).

From the 36 Type I (or Type I/II mixtures) eclogitic diamonds, 59 coupled $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N values were obtained. $\delta^{15}\text{N}$ -values range from -11.1 to +4.6 ‰, a mean $\delta^{15}\text{N}$ at \sim -2.4‰, most values (\sim 77%) being negative (Figure 5). Negative (i.e. as opposed to positive) $\delta^{15}\text{N}$ -values also occur among two low $\delta^{13}\text{C}$ -diamonds. Among duplicate $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N analyses ($n = 22$) diamonds show again, overall, good agreements between the two $\delta^{13}\text{C}$ (< 0.6 ‰, $n = 19$), $\delta^{15}\text{N}$ (< 2 ‰, $n = 18$) and N-content (< 200 ppm, $n = 12$) values. Among samples for which heterogeneity has been detected, no simple relationship between the different parameters has been detected. For example, sample DP 425 ($n = 3$) showed a 1.5‰ $\delta^{13}\text{C}$ -range (from -6.6 to -5.1‰) variations being negatively correlated to $\delta^{15}\text{N}$ (from -5.5 to -2.6‰) with no relation with N-contents. Sample DP361 shows a $\delta^{13}\text{C}$ range of 0.8‰ (from -5.3 to -4.4‰) the variations being positively correlated with both $\delta^{15}\text{N}$ (from -4.3 to +4.4) and N-contents (from 560 to 200 ppm). Sample DP 514 displays a range of 0.5‰ (from -4.2 to -3.7‰) the variations being negatively correlated with $\delta^{15}\text{N}$. As shown by Figure 5, with the exception of two eclogitic diamonds having low $\delta^{13}\text{C}$ -values, eclogitic and peridotitic diamonds cover nearly identical $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ fields.

DISCUSSION

Diamonds of different parageneses have different $\delta^{13}\text{C}$ -ranges, mean, $\delta^{13}\text{C}$ -values, etc... and these results could be interpreted according to a model involving several and distinct carbon sources.

However, it is of major importance to emphasise that the MAIN $\delta^{13}\text{C}$ mode for every

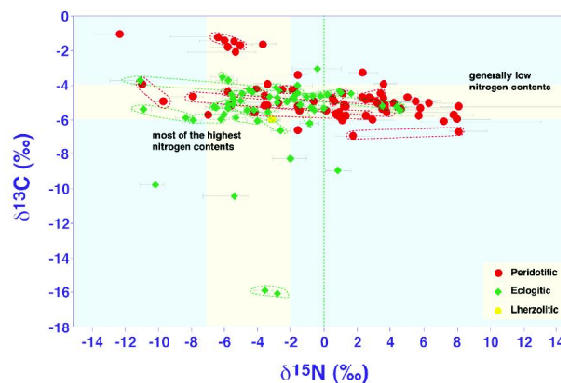
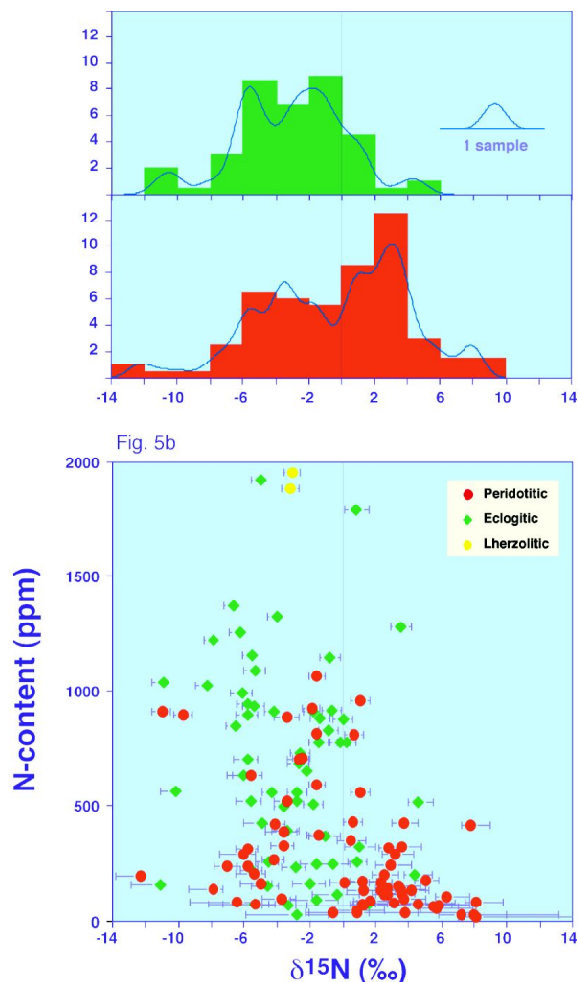


Fig. 5 : $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ relationships among eclogitic and peridotitic diamonds. Note the overlap of most diamonds, with many falling on the so-called mantle-values.

diamond parageneses (harzburgitic, lherzolitic and eclogitic) is the same (at about -5.0‰) within the order of 0.6‰. This fact implies that most peridotitic and eclogitic diamonds from Kimberley Pool crystallised from a same carbon source. The evidence brought by carbon isotopes is strengthened when nitrogen isotopes are considered, eclogitic and peridotitic overlapping a nearly identical field in a $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ space. Although covering a large $\delta^{15}\text{N}$ -range, from H² -12 to +8‰, the fact that $\delta^{15}\text{N}$ -values are centered around -5‰, demonstrates that the main carbon source identified above is mantle-derived.

The present data bring additional facts arguing against a formation of eclogitic diamonds and peridotitic diamonds from two (or more) distinct carbon source. Moreover, systematic $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N-contents covariations rule out any mixing relationship involving a lower (or higher) $\delta^{13}\text{C}$ component to account for the large $\delta^{15}\text{N}$ range (-12 to +8‰). If the large $\delta^{15}\text{N}$ -range is produced by a mixing process, the second carbon source would need to be characterised by a $\delta^{13}\text{C}$ -value close to -6‰.

The implication of the $\delta^{13}\text{C}$ - $\delta^{15}\text{N}$ -N trends will be discussed at the conference in terms of compatibility versus incompatibility of nitrogen with respect to diamond during growth.



The present results have also implications on models calling for a primordial heterogeneity. The fact that eclogitic and peridotitic diamonds have the same main mode demonstrates that the carbon provided below the Kimberley area is rather well homogenised and not primarily heterogeneous on local scale.

Peridotitic and eclogitic diamonds below Kimberley formed in the Archean (Richardson et

al., 1984, 2001) and given that most eclogitic and eclogitic diamonds have the same carbon, we infer that carbon isotopic composition remained constant over geological periods; in agreement with the surface sedimentary record.

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